Demonstration of a Software Defined Visible Light Communication System

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Abstract

Software Defined Radio (SDR) has proven to be an effective and practical tool in the area of RF communication systems, essentially allowing flexible and rapid exploration of signal processing techniques for RF. The software defined concept can also be adapted to other physical communication media; we consider an optical channel.

Visible Light Communication (VLC) uses the visible light spectrum as a medium for data transfer. This topic has gained recent interest due to the ubiquity of emerging solid-state lighting provided by "white" LEDs. We demonstrate a Software Defined VLC (SDVLC) solution implementing an illumination quality optical front end to adapt an SDR platform to the VLC channel. Utilization of such a system allows for quick implementation of new testing scenarios in order to facilitate research in VLC. This demonstration is eligible for the student demo competition and is led by Michael Rahaim and Ali Mirvakili.

Keywords – Software Defined Radio, Visible Light Communication, LEDs, Video Streaming

1. Demonstration Description

Our SDVLC system implements the GNURadio platform with a VLC front-end. GNURadio is a free software development toolkit for runtime signal processing that interacts with external hardware typically used for transmitting RF signals. We utilize this hardware, namely the Universal Software Radio Peripheral (USRP) with low frequency transmitter and receiver (LFTX / LFRX), as an interface to an optical front end in order to create a point to point VLC link.

Figure 1: Real time video streaming from PC1 (left) to PC2 (right) over a 1m VLC link (center). The system is capable of transmitting over a distance of 3m.

Our demonstration shows the use of illumination quality lighting to provide a 1Mb/s real time video stream over a distance of 3 meters. Raw data from a UVC compatible webcam is first converted to streaming media via a GStreamer application. This video stream is then passed through GNURadio to the USRP in order generate the low frequency modulation schemes presented to our optical transmitter. The optical front end consists of an analog LED driver and amplified photodetector that converts the optical signal back to an electrical signal. This signal is received by the second USRP, demodulated and passed to a media player.

Our demonstration illustrates first and foremost the potential for industrial lighting systems to obtain the dual-use capability of VLC. Broadcast VLC provides an alternative channel to RF in multiuser scenarios where the RF channel alone would become congested. As a broadcast transmission medium, VLC has high potential to alleviate RF congestion from distribution services such as the video streaming application seen here.
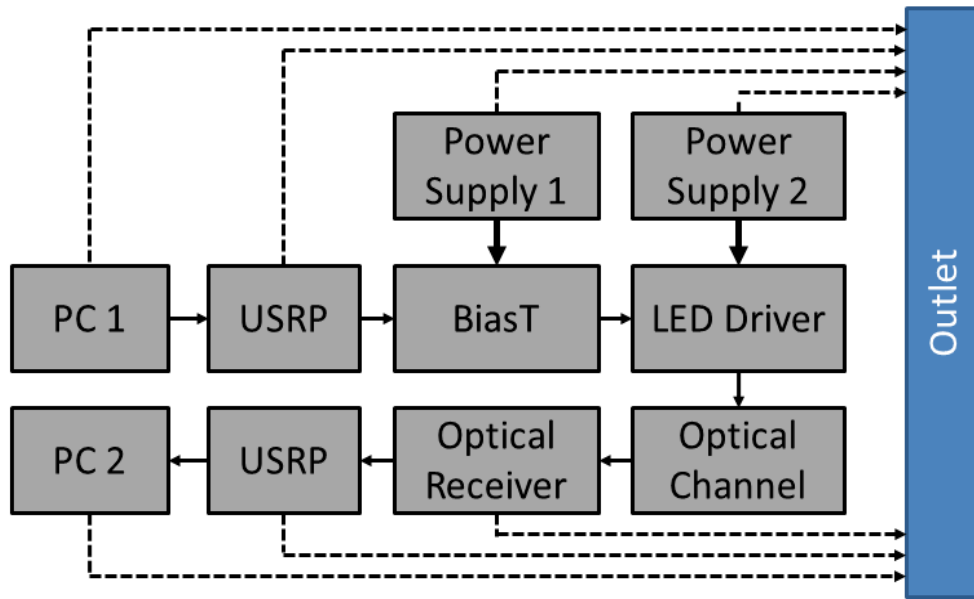
Figure 2: SDVLC Signal Chain

Additionally, we demonstrate the flexibility of a software defined system to operate with different combinations of signal processing schemes and front-end hardware. As a testbed application, we are able to quickly modify the signal processing chain regarding modulation, filters or control codes and test with any of the LED drivers we have implemented.

2. SDVLC Front End Hardware

At the transmitter, the USRP provides digital to analog conversion for implementing the baseband component of the signal. The LFTX modulates this signal onto a carrier frequency for passband modulation. Due to peak voltage limitations of this output, the signal is biased in order to operate within a linear range of the LED driver. The driver then places the modulated signal onto the optical channel. At the receiver, the optical signal is passed through a condensing lens to a photodetector with transimpedance amplifying circuit. The output of the amplified photodetector is then passed to the LFRX at a second USRP where it is converted back to a digitally sampled signal for processing at the receiving PC.

The LED driver in Figure 3 acts as an optical transmitter in the system. It is composed of 16 identical LEDs, each tied to the same drive signal and in series with a MOSFET (M), a limiting resistor (R) and power supply. The light emitted from each LED is controlled by the MOSFET which generates a current proportional to the level of incoming voltage from the USRP. This voltage has a DC component as well as an AC component. The DC keeps the transistor in its saturation region and the AC component modulates the LED. The 16 LEDs are divided into two groups that can be powered by separate supply voltages (V_{dd1} and V_{dd2}), while the gates of all 16 MOSFETs are connected together. In this design, we use Osram Semiconductor LEDs (LUW CN5M) and MOSFETs (2N7002).

At the receiver, we utilize a commercial photodetector (Thorlabs – PDA36A) along with an aspheric condensing lens (Thorlabs – ALC2520-A). The detector employs a PIN silicon photodiode with active area of 13mm^2 and a responsivity of 0.2-0.4 A/W in the visible range, depending on wavelength of incoming light. It is set in a transimpedance amplifier configuration with adjustable gain. We use the 10 dB setting, at which the bandwidth is 12.5 MHz, so that the receiver has sufficient bandwidth to match the transmitter.

3. SDVLC Signal Processing

Since GNURadio has been developed primarily for RF communications, the majority of the implemented modulation schemes are meant for high frequency passband. These techniques include Minimum Shift Keying (MSK), Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM). Implementation of a VLC link with passband modulation was attainable with the signal processing blocks available in the GNURadio library. For low data rate transmission, we were able to modulate a 4 MHz carrier frequency onto the optical channel using the LED Driver described in the previous section. After biasing the output from the USRP, the carrier provides a centralized average signal at the receiver and allows the received signal to be observed at the LFRX just as if it were low frequency RF.

In addition to the basic techniques, we have also had success in testing the Orthogonal Frequency Division Multiplexing (OFDM) schemes implemented within GNURadio. The testing we have done includes modulation with binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK). The OFDM schemes implement an FFT of length 2048 and digital up/down conversion for sampling rates of 1 MS/s in order to allow for real time processing. We have achieved real time data rates up to 2 Mb/s with the OFDM implementation.
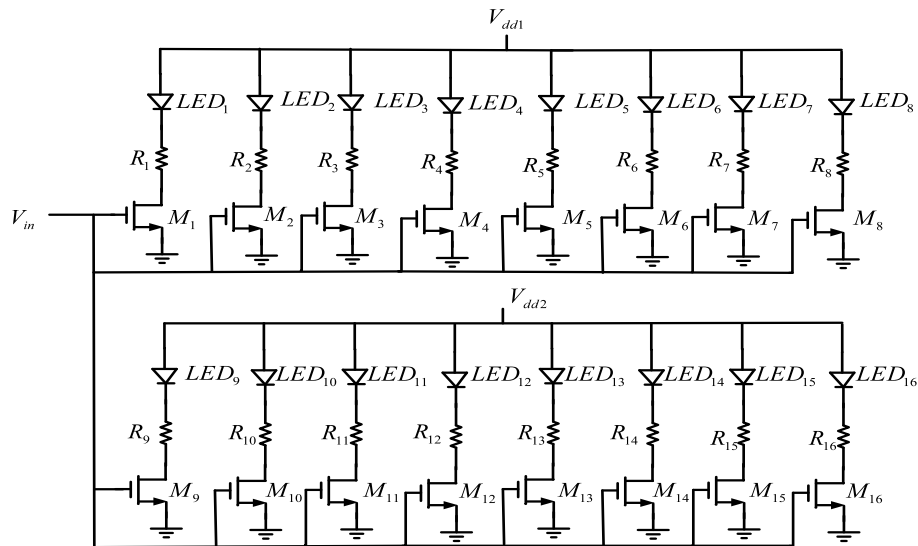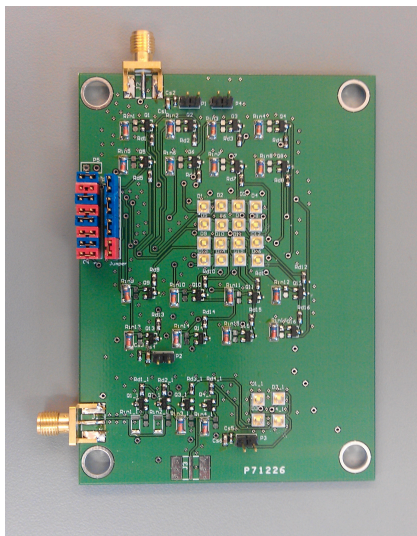

Figure 3: LED Driver and Schematic

Demonstration Requirements: The majority of the items required will be brought by the demonstration group. The only requirement from the conference will be a power strip with at least 8 outlets. The demonstration will take approximately 1 hour to set up and can be displayed on a 4' table.